An Agent-Based Model for Simulating Red Flour Beetle Movement and Population Dynamics

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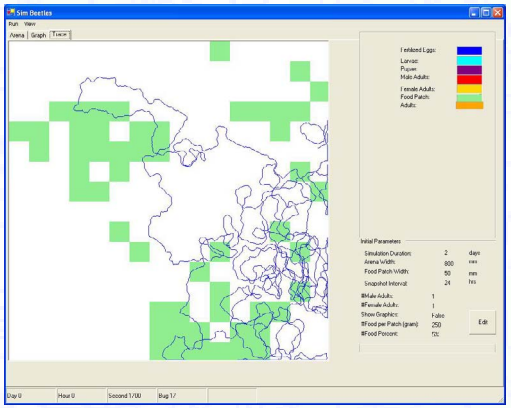
Introduction

Red flour beetle (*Tribolium castaneum*) is a common insect pest infesting flour mills. Over the last 80 years, dozens of mathematical models have been developed to simulate its population dynamics. However, while these models predict general population trends, they are not able to simulate individual behavior and movement, and most don't include a spatial dimension. We built an agent-based model to explicitly represent individual beetles, fragmented landscapes, and the interactions between beetles as well as the interactions between beetles and their environment. Our model can be easily adjusted to different flour landscapes and different scales. The population dynamics, age structure, spatial distribution and movement behaviors are investigated in this agent-based model.



SimBeetle Model: food patches in green, beetle trace in blue. The movement of an individual beetle was traced each second.

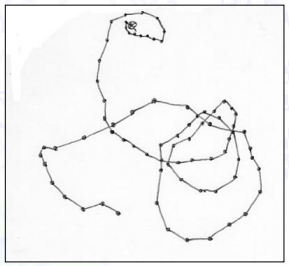
Materials and Methods

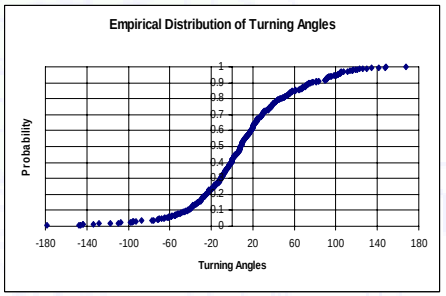
- simBeetle was developed in Microsoft VB.NET, an object-oriented software development tool.
- Beetles are simulated individually. Each beetle goes through its lifecycle: egg, larvae, pupae and adult. Their positions, physical activities, hunger level, and female fertility are modeled.
- Physiological activities, such as feeding and mating, are modeled.
- Population changes are recorded.
- Actual experiments monitoring beetle movement were conducted in 50 by 50 cm^2 arenas.
- MS Excel and SAS were used for data processing and statistical analysis.

Results

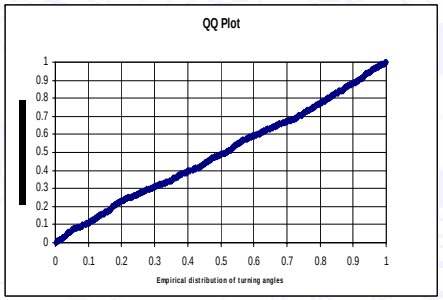
Beetle Movement Paths

Turning angle data were collected during actual experiments with red flour beetle. Individual beetles were placed in a 50 by 50 cm^2 arena, and their positions were recorded every 2 seconds.





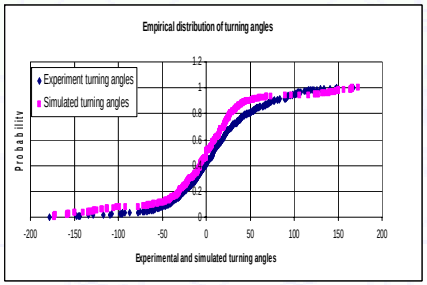
Statistical tests of experimental turning angle distribution

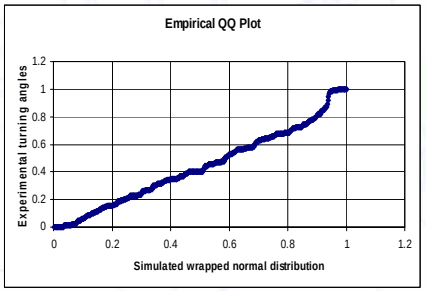


- Rayleigh Test for uniformity P < 0.0001
- Wilcoxon sign-rank test for symmetry at 0 degree P = 0.00005 Mean degree = 11.19
- Cramer-von Mises goodness of fit test for normality P = 0.005
- Watson U^2 goodness of fit test for von Mises distribution Watson U^2 = 0.106717 P = 0.24
- Mean angle = 0.095 (radian)
- von Mises parameter k = 2.25

Simulating beetle movement in SimBeetle

The turning angle is modeled using a wrapped normal distribution because it is very similar to the von Mises distribution, and it is faster to calculate in the SimBeetle program.





Summary

We developed a spatially explicit, agent-based model to better understand and predict beetle population dynamics in spatially complex landscapes. Because an agent-based model allows for differences in agent behavior and competition between agents, these models can be more realistic than deterministic models, which have a number of limitations, such as oversimplification of the system and their inability to portray stochastic factors and behavioral interactions. An object-oriented language was used to simulate the behavior of beetles. The model allows movement of individual beetles to be traced. The simulated movement of beetles was compared to actual movement data for red flour beetle in experimental arenas. After analyzing the circular data from biological experiments, a von Mises distribution was found to fit the turning angles of walking adult beetles well. A wrapped normal distribution also fit the data well, and was faster to compute than the von Mises distribution.